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FIG.14

S024

**ENTRY** 

S200-1

DETERMINE FIRST MODEL NORMAL TURNING GAIT THAT SATISFIES BOUNDARY CONDITION ON THE BASIS OF NORMAL TURNING GAIT PARAMETER BY USING FIRST MODEL AND DETERMINE FIRST MODEL INITIAL (AT Ts) BODY HORIZONTAL POSITION, VELOCITY, ANGULAR VELOCITY, AND BODY INCLINATION RESTORING MOMENT ZMP-CONVERTED VALUE PEAK VALUES (Xs1, Vxs1,  $\omega$ bs1, ZMPrecpeak1).

S200-2

USING SECOND MODEL, TAKE (Xs1, Vxs1,  $\omega$ bs1, ZMPrecpeak1) AS SEARCH INITIAL VALUES, AND SEARCH FOR SECOND MODEL NORMAL TURNING GAIT THAT SATISFIES BOUNDARY CONDITION ON THE BASIS OF THE SEARCH INITIAL VALUES AND OTHER NORMAL TURNING GAIT PARAMETER, AND DETERMINE SECOND MODEL INITIAL (AT Ts) BODY HORIZONTAL POSITION, VELOCITY, ANGULAR VELOCITY, AND BODY INCLINATION RESTORING MOMENT ZMP-CONVERTED VALUE PEAK VALUES (Xs2, Vxs2,  $\omega$ bs2, ZMPrecpeak2).

S200-n

USING n-TH MODEL, TAKE (Xsm, Vxsm,  $\omega$ bsm, ZMPrecpeakm)(WHERE m=n-1) AS SEARCH INITIAL VALUES, AND SEARCH FOR n-TH MODEL NORMAL TURNING GAIT THAT SATISFIES BOUNDARY CONDITION ON THE BASIS OF THE SEARCH INITIAL VALUES AND OTHER NORMAL TURNING GAIT PARAMETER, AND DETERMINE n-TH MODEL INITIAL (AT Ts) BODY HORIZONTAL POSITION, VELOCITY, ANGULAR VELOCITY, AND BODY INCLINATION RESTORING MOMENT ZMP-CONVERTED VALUE PEAK VALUES (Xsn, Vxsn,  $\omega$ bsn, ZMPrecpeakn).

\$204

BASED ON n-TH MODEL NORMAL TURNING GAIT, DETERMINE n-TH MODEL INITIAL BODY POSITION, VELOCITY, POSTURE ANGLE, ANGULAR VELOCITIES (X0n, Vx0n,  $\theta$  b0n,  $\omega$ b0n), AND INITIAL BODY VERTICAL POSITION/VELOCITY (Z0n,Vz0n) AT ORIGINAL INITIAL TIME 0.

DETERMINE n-TH MODEL NORMAL TURNING INITIAL DIVERGENCE COMPONENT q[0] BY USING THE FOLLOWING EXPRESSION:

\$222

 $q[0] = X0n + Vx0n / \omega 0$ 

S224

DETERMINE q'', WHICH DENOTES VALUE OF n-TH MODEL NORMAL TURNING INITIAL DIVERGENCE COMPONENT q[0] observed from supporting Leg coordinate system of current time's gait, and determine (z0",vz0"), which denote values of n-TH model initial body vertical position/velocity observed from supporting Leg coordinate system of current time's gait.

## **FIG.15**

S200-1 **ENTRY S250** DETERMINE INITIAL STATES (STATES AT INITIAL TIME Ts) OF FOOT POSITION/POSTURE, BODY POSTURE ANGLE  $\, heta$  bs, and arm posture on the basis of normal turning gait parameter PROVISIONALLY DETERMINE FIRST MODEL INITIAL (AT Ts) BODY HORIZONTAL POSITION, VELOCITY, ANGULAR VELOCITY, AND BODY INCLINATION RESTORING MOMENT ZMP-CONVERTED VALUE PEAK VALUE CANDIDATES (Xs1, Vxs1,  $\omega$  bs1, ZMPrecpeak1). \$256 DETERMINE FIRST MODEL INITIAL BODY VERTICAL POSITION/VELOCITY (Zs1, Vzs1). USING FIRST DYNAMIC MODEL, GENERATE FIRST MODEL GAIT ON THE BASIS OF NORMAL TURNING GAIT PARAMETER INCLUDING ZMPrecpeak1, TAKING  $\theta$  bs1,(Xs1, Vxs1,  $\omega$ bs1), (Zs1,Vzs1) AS INITIAL STATES OF BODY. **S260** CONVERT BODY HORIZONTAL POSITION, VELOCITY, POSTURE ANGLE, AND ANGULAR VELOCITY AT TERMINATING END OF GENERATED GAIT INTO VALUES OBSERVED FROM SUPPORTING LEG COORDINATE SYSTEM OF NEXT STEP, AND DENOTE THE CONVERTED VALUES AS (Xe1, Vxe1, heta be1,  $\omega$  be1). **S262** S254 BOUNDARY CONDITION ERRORS (errx, errv, err  $\theta$ , err  $\omega$ ) = (Xs1, Vxs1,  $\theta$  bs1,  $\omega$ bs1)-(Xe1, Vxe1,  $\theta$  be1,  $\omega$ be1)  $\infty$ yes LEAVE REPETITION LOOP. ARE ALL errx, errv, err  $\theta$ , AND  $err \omega$  WITHIN PERMISSIBLE RANGES? **S266** DETERMINE A PLURALITY OF CANDIDATES (Xs1+ $\triangle$  Xs, Vxs1,  $\omega$ bs1, ZMPrecpeak1), (Xs1, Vxs1+ $\triangle$ Vxs,  $\omega$ bs1, ZMPrecpeak1), (Xs1, Vxs1,  $\omega$ bs1+ $\triangle$   $\omega$ bs, ZMPrecpeak1), (Xs1, Vxs1,  $\omega$  bs1, ZMPrecpeak1+ $\triangle$  ZMPrecpeak) IN THE VICINITY OF (Xs1, Vxs1,  $\omega$ bs1, ZMPrecpeak1), AND BASED ON THEM, DETERMINE BOUNDARY CONDITION ERROR CORRESPONDING TO EACH OF THEM AS DESCRIBED ABOVE. S268 DETERMINE NEW CANDIDATES (Xs1, Vxs1,  $\omega$ bs1, ZMPrecpeak1) ON THE BASIS OF BOUNDARY CONDITION ERRORS CORRESPONDING TO (Xs1, Vxs1, ωbs1, ZMPrecpeak1) AND EACH OF CANDIDATES IN THE VICINITY THEREOF.

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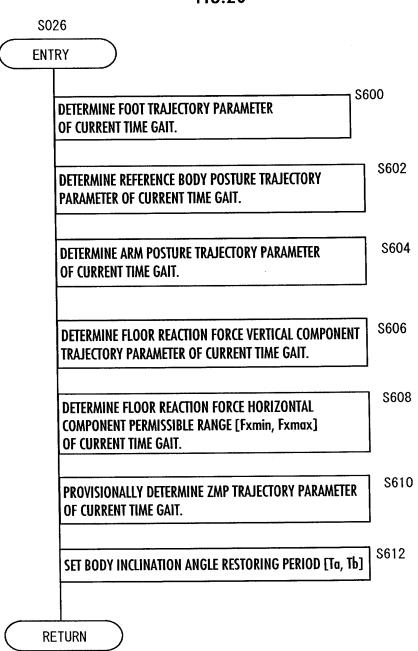
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## **FIG.16**

 $S202-n (n \ge 2)$ **ENTRY** S1200 DETERMINE INITIAL STATES (STATES AT INITIAL TIME Ts) OF FOOT POSITION/POSTURE, BODY POSTURE ANGLE  $\theta$  bs, and arm posture on the basis of normal turning gait parameter. SUBSTITUTE (Xsm, Vxsm,  $\omega$  bsm, ZMPrecpeakm)(WHERE m=n-1) INTO n-TH MODEL INITIAL (AT Ts) BODY  $^{S1202}$ HORIZONTAL POSITION, VELOCITY, ANGULAR VELOCITY, AND BODY INCLINATION RESTORING MOMENT ZMP-CONVERTED VALUE PEAK VALUE CANDIDATES (Xsn, Vxsn, \omega\text{bsn}, ZMPrecpeakn). S1206 DETERMINE n-TH MODEL INITIAL BODY VERTICAL POSITION/VELOCITY (Zsn, Vzsn). S1208 USING n-TH DYNAMIC MODEL, GENERATE n-TH MODEL GAIT ON THE BASIS OF NORMAL TURNING GAIT PARAMETER INCLUDING ZMPrecpeakn, TAKING  $\theta$  bsn,(Xsn, Vxsn,  $\omega$ bsn), (Zsn, Vzsn) AS INITIAL STATES OF BODY. S1210 CONVERT BODY HORIZONTAL POSITION, VELOCITY, POSTURE ANGLE, AND ANGULAR VELOCITY AT TERMINATING END OF GENERATED GAIT INTO VALUES OBSERVED FROM SUPPORTING LEG COORDINATE SYSTEM OF NEXT STEP, AND DENOTE THE CONVERTED VALUES AS (Xen, Vxen,  $\theta$  ben,  $\omega$ ben). S1212 BOUNDARY CONDITION ERRORS (errx, errv, err  $\theta$ , err  $\omega$ ) S1204 = (Xsn, Vxsn,  $\theta$  bsn,  $\omega$  bsn)-(Xen, Vxen,  $\theta$  ben,  $\omega$  ben) S1214 yes  $\infty$ LEAVE REPETITION LOOP. ARE ALL errx, errv, err  $\theta$ , AND err  $\omega$ WITHIN PERMISSIBLE RANGES? S1216 DETERMINE A PLURALITY OF CANDIDATES (Xsn+ $\triangle$  Xs, Vxsn,  $\omega$ bsn, ZMPrecpeakn), (Xsn, Vxsn+ $\triangle$ Vxs,  $\omega$ bsn, ZMPrecpeakn), (Xsn, Vxsn,  $\omega$ bsn+ $\triangle$   $\omega$ bs, ZMPrecpeakn), (Xsn, Vxsn,  $\omega$ bsn, ZMPrecpeakn+ $\Delta$  ZMPrecpeak) IN THE VICINITY OF (Xsn, Vxsn, ωbsn, ZMPrecpeakn), AND BASED ON THEM, DETERMINE BOUNDARY CONDITION ERROR CORRESPONDING EACH OF THEM AS DESCRIBED ABOVE. S1218 DETERMINE NEW CANDIDATES (Xsn, Vxsn,  $\omega$ bsn, ZMPrecpeakn) ON THE BASIS OF BOUNDARY CONDITION ERRORS CORRESPONDING TO (Xsn, Vxsn,  $\omega$  bsn, ZMPrecpeakn) AND EACH OF CANDIDATES IN THE VICINITY THEREOF.

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## **FIG.21**

S028

**ENTRY** 

USING FIRST MODEL, DETERMINE (a1, ZMPrecpeaka1, ZMPrecpeakb1), WHICH ARE VALUES OF (a, ZMPrecpeaka, ZMPrecpeakb) FOR FIRST MODEL CURRENT TIME GAIT TO BE GENERATED TO SATISFY BOUNDARY CONDITION, ON THE BASIS OF CURRENT TIME GAIT PARAMETER.

S700-2

S700-1

USING SECOND MODEL, TAKE (a1, ZMPrecpeaka1, ZMPrecpeakb1) AS SEARCH INITIAL VALUES AND DETERMINE (a2, ZMPrecpeaka2, ZMPrecpeakb2), WHICH ARE VALUES OF (a, ZMPrecpeaka, ZMPrecpeakb) FOR SECOND MODEL CURRENT TIME GAIT TO BE GENERATED TO SATISFY BOUNDARY CONDITION, ON THE BASIS OF THE ABOVE SEARCH INITIAL VALUES AND OTHER CURRENT TIME GAIT PARAMETER.

USING n-TH MODEL, TAKE (am, ZMPrecpeakam, ZMPrecpeakbm)(WHERE m=n-1) AS SEARCH INITIAL VALUES AND DETERMINE (an, ZMPrecpeakn, ZMPrecpeakbn), WHICH ARE VALUES OF (a, ZMPrecpeaka, ZMPrecpeakb) FOR n-TH MODEL CURRENT TIME GAIT TO BE GENERATED TO SATISFY BOUNDARY CONDITION, ON THE BASIS OF THE ABOVE SEARCH INITIAL VALUES AND OTHER CURRENT TIME GAIT PARAMETER.

S700-n

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22 / 27 **FIG.22** 

S700-1

**ENTRY** 

S750

PROVISIONALLY DETERMINE FIRST MODEL ZMP CORRECTION PARAMETER CANDIDATE a1 AND BODY INCLINATION RESTORING MOMENT ZMP-CONVERTED VALUE PEAK VALUE CANDIDATES (ZMPrecpeaka1, ZMPrecpeakb1).

**S754** 

**S756** 

CALCULATE FIRST MODEL CURRENT TIME GAIT UNTIL TERMINATING TIME BY USING FIRST MODEL ON THE BASIS OF PARAMETER OBTAINED BY CORRECTING ZMP TRAJECTORY PARAMETER, WHICH HAS BEEN PROVISIONALLY DETERMINED BY PROVISIONAL DETERMINING PROCESSING OF CURRENT TIME GAIT, BY ZMP CORRECTION PARAMETER CANDIDATE  $\mathfrak a1$ , BODY INCLINATION RESTORING MOMENT ZMP-CONVERTED VALUE PEAK VALUE CANDIDATE (ZMPrecpeaka1, ZMPrecpeakb1), AND OTHER CURRENT TIME GAIT PARAMETER.

DETERMINE TERMINAL DIVERGENCE COMPONENT q0[k]

ACCORDING TO THE FOLLOWING EXPRESSION FROM BODY POSITION/VELOCITY (Xe1, Ve1) AT TERMINATING END OF CURRENT TIME GAIT:

 $q01[k] = Xe1 + Vxe1 / \omega 0$ 

DETERMINE TERMINAL DIVERGENCE COMPONENT ERROR error ACCORDING TO THE FOLLOWING EXPRESSION:

\$758

errq = q01[k] - q''

\$760

**S764** 

TERMINAL BODY INCLINATION ANGLE ERROR  $\theta$  berr

- = n-TH MODEL NORMAL GAIT INITIAL BODY INCLINATION ANGLE
  - FIRST MODEL CURRENT TIME GAIT TERMINAL BODY INCLINATION ANGLE

TERMINAL BODY INCLINATION ANGULAR VELOCITY ERROR  $\omega$  berr

- = n-TH MODEL NORMAL GAIT INITIAL BODY INCLINATION ANGULAR VELOCITY
  - FIRST MODEL CURRENT TIME GAIT TERMINAL BODY INCLINATION ANGULAR VELOCITY

S762 yes

LEAVE REPETITION LOOP.

ARE ALL errq,  $\theta$  berr, AND  $\omega$  berr

**S752** 

WITHIN PERMISSIBLE RANGES?  $\infty$ 

DETERMINE A PLURALITY OF INITIAL VALUE CANDIDATES (a1 +  $\triangle$  a, ZMPrecpeaka1, ZMPrecpeakb1),

(a1, ZMPrecpeaka1 + △ZMPrecpeaka, ZMPrecpeakb1), AND

- (a1, ZMPrecpeaka1, ZMPrecpeakb1 + △ZMPrecpeakb) IN THE VICINITY OF
- (a1, ZMPrecpeaka1, ZMPrecpeakb1), AND BASED ON THEM, DETERMINE ERROR CORRESPONDING TO EACH OF THEM AS DESCRIBED ABOVE.

DETERMINE NEW PARAMETER CANDIDATES (a1, ZMPrecpeaka1, ZMPrecpeakb1) ON THE BASIS OF (a1, ZMPrecpeaka1, ZMPrecpeakb1) AND ERROR CORRESPONDING TO EACH OF INITIAL VALUE CANDIDATES IN THE VICINITY THEREOF.

**\$766** 

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**FIG.23** 

\$700-n (n≥2)

**ENTRY** 

S1700

SUBSTITUTE am AND (ZMPrecpeakam, ZMPrecpeakbm)(WHERE m=n-1) INTO n-TH MODEL ZMP CORRECTION PARAMETER CANDIDATE on AND BODY INCLINATION RESTORING MOMENT ZMP-CONVERTED VALUE PEAK VALUE CANDIDATE (ZMPrecpeakan, ZMPrecpeakbn), RESPECTIVELY.

S1704

S1706

CALCULATE n-TH MODEL CURRENT TIME GAIT UNTIL TERMINATING TIME BY USING n-TH MODEL ON THE BASIS OF PARAMETER OBTAINED BY CORRECTING ZMP PARAMETER, WHICH HAS BEEN PROVISIONALLY DETERMINED BY PROVISIONAL DETERMINING PROCESSING OF CURRENT TIME GAIT, BY ZMP CORRECTION PARAMETER CANDIDATE an, BODY INCLINATION RESTORING MOMENT ZMP-CONVERTED VALUE PEAK VALUE CANDIDATE (ZMPrecpeakan, ZMPrecpeakbn), AND OTHER CURRENT TIME GAIT PARAMETER.

DETERMINE TERMINAL DIVERGENCE COMPONENT q0[k] FROM BODY HORIZONTAL POSITION/VELOCITY (Xen, Ven) AT TERMINATING END OF CURRENT TIME GAIT ACCORDING TO THE FOLLOWING EXPRESSION:  $q0n[k] = Xen + Vxen / \omega 0$ 

DETERMINE TERMINAL DIVERGENCE COMPONENT ERROR errq ACCORDING TO THE FOLLOWING EXPRESSION:

S1708

erra = a0n[k] - a''

TERMINAL BODY INCLINATION ANGLE ERROR  $\theta$  berr

= n-TH MODEL NORMAL GAIT INITIAL BODY INCLINATION ANGLE

 n-TH MODEL CURRENT TIME GAIT TERMINAL BODY INCLINATION ANGLE TERMINAL BODY INCLINATION ANGULAR VELOCITY ERROR  $\omega$ berr

= n-TH MODEL NORMAL GAIT INITIAL BODY INCLINATION ANGULAR VELOCITY

n-TH MODEL CURRENT TIME GAIT TERMINAL BODY INCLINATION ANGULAR VELOCITY

S1712 yes

LEAVE REPETITION LOOP.

 $\infty$ 

S1702

ARE ALL errq.  $\theta$  berr, AND  $\omega$  berr WITHIN PERMISSIBLE RANGES?

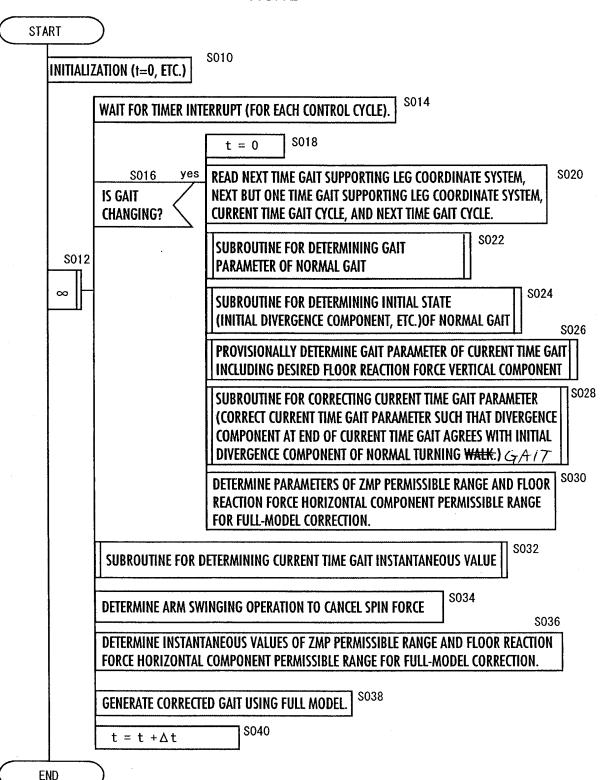
S1714

S1710

DETERMINE A PLURALITY OF INITIAL VALUE CANDIDATES (an+  $\triangle$  a, ZMPrecpeakan, ZMPrecpeakbn), (an, ZMPrecpeakan + △ZMPrecpeaka, ZMPrecpeakbn), AND (an, ZMPrecpeakan, ZMPrecpeakbn + △ ZMPrecpeakb) IN THE VICINITY OF (an, ZMPrecpeakan, ZMPrecpeakbn), AND BASED ON THEM, DETERMINE ERROR CORRESPONDING TO EACH OF THEM AS DESCRIBED ABOVE.

DETERMINE NEW PARAMETER CANDIDATES (an, ZMPrecpeakan, ZMPrecpeakbn) ON THE BASIS OF (an, ZMPrecpeakan, ZMPrecpeakbn) AND ERROR CORRESPONDING TO EACH OF INITIAL VALUE CANDIDATES IN THE VICINITY THEREOF.

S1716



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**FIG.14** 

S024

**ENTRY** 

S200-1

DETERMINE FIRST MODEL NORMAL TURNING GAIT THAT SATISFIES BOUNDARY CONDITION ON THE BASIS OF NORMAL TURNING GAIT PARAMETER BY USING FIRST MODEL AND DETERMINE FIRST MODEL INITIAL (AT  $t_s$ ) body horizontal position, velocity, angular velocity, and body inclination restoring moment ZMP-converted value peak values (Xs1, Vxs1,  $\omega$ bs1, ZMPrecpeek1).

a

\$200-2

USING SECOND MODEL, TAKE (Xs1, Vxs1, ωbs1, ZMPrecpeek1) AS SEARCH INITIAL VALUES, AND SEARCH FOR SECOND MODEL NORMAL TURNING GAIT THAT SATISFIES BOUNDARY CONDITION ON THE BASIS OF THE SEARCH INITIAL VALUES AND OTHER NORMAL TURNING GAIT PARAMETER, AND DETERMINE SECOND MODEL INITIAL (AT Ts) BODY HORIZONTAL POSITION, VELOCITY, ANGULAR VELOCITY, AND BODY INCLINATION RESTORING MOMENT ZMP-CONVERTED VALUE PEAK VALUES (Xs2, Vxs2, ωbs2, ZMPrecpeek2).

S200-n

USING n-TH MODEL, TAKE (Xsm, Vxsm, ωbsm, ZMPrecpeèkm)(WHERE m=n-1) AS SEARCH INITIAL VALUES, AND SEARCH FOR n-TH MODEL NORMAL TURNING GAIT THAT SATISFIES BOUNDARY CONDITION ON THE BASIS OF THE SEARCH INITIAL VALUES AND OTHER NORMAL TURNING GAIT PARAMETER, AND DETERMINE n-TH MODEL INITIAL (AT Ts) BODY HORIZONTAL POSITION, VELOCITY, ANGULAR VELOCITY, AND BODY INCLINATION RESTORING MOMENT ZMP-CONVERTED VALUE PEAK VALUES (Xsn, Vxsn, ωbsn, ZMPrecpeèkn).

S204

BASED ON n-TH MODEL NORMAL TURNING GAIT, DETERMINE n-TH MODEL INITIAL BODY POSITION, VELOCITY, POSTURE ANGLE, ANGULAR VELOCITIES (X0n,  $V_{x}$ 0n,  $\theta$  b0n,  $\omega$  b0n), AND INITIAL BODY VERTICAL POSITION/VELOCITY (Z0n, $V_{z}$ 0n) AT ORIGINAL INITIAL TIME 0.

DETERMINE n-TH MODEL NORMAL TURNING INITIAL DIVERGENCE COMPONENT q[0] BY USING THE FOLLOWING EXPRESSION:

S222

 $q[0] = X0n + Vx0n / \omega 0$ 

**S224** 

DETERMINE q", WHICH DENOTES VALUE OF n-TH MODEL NORMAL TURNING INITIAL DIVERGENCE COMPONENT q[0] OBSERVED FROM SUPPORTING LEG COORDINATE SYSTEM OF CURRENT TIME'S GAIT, AND DETERMINE (Z0",Vz0"), WHICH DENOTE VALUES OF n-TH MODEL INITIAL BODY VERTICAL POSITION/VELOCITY OBSERVED FROM SUPPORTING LEG COORDINATE SYSTEM OF CURRENT TIME'S GAIT.

## **FIG.15**

\$200-1 **ENTRY** S250 DETERMINE INITIAL STATES (STATES AT INITIAL TIME Ts) OF FOOT POSITION/POSTURE, BODY POSTURE ANGLE heta bs. and arm posture on the basis of normal turning gait parameter. PROVISIONALLY DETERMINE FIRST MODEL INITIAL (AT Ts) BODY HORIZONTAL POSITION, VELOCITY, ANGULAR VELOCITY, AND BODY INCLINATION RESTORING MOMENT ZMP-CONVERTED VALUE PEAK VALUE CANDIDATES (Xs1, Vxs1,  $\omega$ bs1, ZMPrecpeek1). S256 DETERMINE FIRST MODEL INITIAL BODY VERTICAL POSITION/VELOCITY (Zs1, Vzs1). S258 USING FIRST DYNAMIC MODEL, GENERATE FIRST MODEL GAIT ON THE BASIS OF NORMAL TURNING GAIT PARAMETER INCLUDING ZMPrecpeek1, TAKING  $\theta$  bs1,(Xs1, Vxs1,  $\omega$  bs1), (Zs1, Vzs1) AS INITIAL STATES OF BODY. S260 CONVERT BODY HORIZONTAL POSITION, VELOCITY, POSTURE ANGLE, AND ANGULAR VELOCITY AT TERMINATING END OF GENERATED GAIT INTO VALUES OBSERVED FROM SUPPORTING LEG COORDINATE SYSTEM OF NEXT STEP, AND DENOTE THE CONVERTED VALUES AS (Xe1, Vxe1,  $\theta$  be1,  $\omega$  be1). S254 **S262** BOUNDARY CONDITION ERRORS (errx, errv, err  $\theta$ , err  $\omega$ ) = (Xs1, Vxs1,  $\theta$  bs1,  $\omega$ bs1)-(Xe1, Vxe1,  $\theta$  be1,  $\omega$ be1)  $\infty$ LEAVE REPETITION LOOP. ARE ALL errx, erry, err ob, AND Errorb WITHIN PERMISSIBLE RANGES? **S266** DETERMINE A PLURALITY OF CANDIDATES (Xs1+ $\triangle$  Xs, Vxs1,  $\omega$  bs1, ZMPrecpeek1), (Xs1, Vxs1+ $\triangle$ Vxs,  $\omega$ bs1, ZMPrecpeek1), (Xs1, Vxs1,  $\omega$ bs1+ $\triangle$   $\omega$ bs, ZMPrecpeek1), (Xs1, Vxs1, ωbs1, ZMPrecpeĕk1+ ΔZMPrecpeĕk) IN THE VICINITY OF (Xs1, Vxs1, ωbs1, ZMPrecpeck1), AND BASED ON THEM, DETERMINE BOUNDARY CONDITION ERROR CORRESPONDING TO EACH OF THEM AS DESCRIBED ABOVE. **S268** DETERMINE NEW CANDIDATES (Xs1, Vxs1,  $\omega$  bs1, ZMPrecpe $\phi$ k1) ON THE BASIS OF BOUNDARY CONDITION ERRORS CORRESPONDING TO (Xs1, Vxs1,  $\omega$  bs1, ZMPrecpeak1) AND EACH OF CANDIDATES IN THE VICINITY THEREOF.

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### FIG. 16

S202-n(n≥2) **ENTRY** \$1200 DETERMINE INITIAL STATES (STATES AT INITIAL TIME Ts) OF FOOT POSITION/POSTURE, BODY POSTURE ANGLE  $\, heta$  bs, and arm posture on the basis of normal turning gait parameter. SUBSTITUTE (Xsm, Vxsm, ωbsm, ZMPrecpeekm)(WHERE m=n-1) INTO n-TH MODEL INITIAL (AT Ts) BODY S1202 HORIZONTAL POSITION, VELOCITY, ANGULAR VELOCITY, AND BODY INCLINATION RESTORING MOMENT ZMP-CONVERTED VALUE PEAK VALUE CANDIDATES (Xsn, Vxsn, ωbsn, ZMPrecpeekn). S1206 DETERMINE n-TH MODEL INITIAL BODY VERTICAL POSITION/VELOCITY (Zsn, Vzsn). **3**1208 USING n-TH DYNAMIC MODEL, GENERATE n-TH MODEL GAIT ON THE BASIS OF NORMAL TURNING GAIT PARAMETER INCLUDING ZMPrecpeekn, TAKING  $\theta$  bsn,(Xsn, Vxsn,  $\omega$ bsn), (Zsn.Vzsn) AS INITIAL STATES OF BODY. S1210 CONVERT BODY HORIZONTAL POSITION, VELOCITY, POSTURE ANGLE, AND ANGULAR VELOCITY AT TERMINATING END OF GENERATED GAIT INTO VALUES OBSERVED FROM SUPPORTING LEG COORDINATE SYSTEM OF NEXT STEP, AND DENOTE THE CONVERTED VALUES AS (Xen, Vxen,  $\theta$  ben,  $\omega$  ben). S1212 BOUNDARY CONDITION ERRORS (errx, errv, err  $\theta$ , err  $\omega$ ) S1204 = (Xsn, Vxsn,  $\theta$  bsn,  $\omega$ bsn)-(Xen, Vxen,  $\theta$  ben,  $\omega$ ben) \$1214 yes  $\infty$ erra LEAVE REPETITION LOOP. ARE ALL errx, erry, <del>errob,</del> AND <del>errob</del> /evru WITHIN PERMISSIBLE RANGES? S1216 DETERMINE A PLURALITY OF CANDIDATES (Xsn+ △ Xs, Vxsn, ωbsn, ZMPrecpeekn), (Xsn, Vxsn+ ΔVxs, ωbsn, ZMPrecpeekn), (Xsn, Vxsn, ωbsn+ Δωbs, ZMPrecpeekn), (Xsn, Vxsn, ωbsn, ZMPrecpeekn+ △ ZMPrecpeek) IN THE VICINITY OF (Xsn, Vxsn,  $\omega$  bsn, ZMPrecpe $\Phi$ kn), AND BASED ON THEM, DETERMINE BOUNDARY CONDITION ERROR CORRESPONDING EACH OF THEM AS DESCRIBED ABOVE. S1218 DETERMINE NEW CANDIDATES (Xsn, Vxsn,  $\omega$  bsn, ZMPrecpeekn) ON THE BASIS OF BOUNDARY CONDITION ERRORS CORRESPONDING TO (Xsn, Vxsn,  $\omega$  bsn, ZMPrecpeekn) AND EACH OF CANDIDATES IN THE VICINITY THEREOF.

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	S02	26	
_	ENTI	RY	
	T		
	ŀ	DETERMINE FOOT TRAJECTORY PARAMETER	600
	- 1	OF CURRENT TIME GAIT.	
	ľ		
	ļ	DETERMINE REFERENCE BODY POSTURE TRAJECTORY	\$602
	ŀ	PARAMETER OF CURRENT TIME GAIT.	
			•
	Ī	DETERMINE ARM POSTURE TRAJECTORY PARAMETER	S604
		OF CURRENT TIME GAIT.	
		DETERMINE FLOOR REACTION FORCE VERTICAL COMPONENT	<b>S606</b>
	]	TRAJECTORY PARAMETER OF CURRENT TIME GAIT.	
			-
		DETERMINE FLOOR REACTION FORCE HORIZONTAL	] S608
		COMPONENT HIMT RANGE [Fxmin, Fxmax]	
		OF CURRENT TIME GAIT.  PERMISSIBLE	
		PROVISIONALLY DETERMINE ZMP TRAJECTORY PARAMETER	<b>3610</b>
		OF CURRENT TIME GAIT.	
		SET BODY INCLINATION ANGLE RESTORING PERIOD [Ta, Tb]	S612
		SET BODY INCLINATION ANGLE RESTORTED LINE [14, 15]	_
	RF1	TURN	
/			

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## **FIG.21**

\$028

**ENTRY** 

USING FIRST MODEL, DETERMINE (a1, ZMPrecpeaka1, ZMPrecpeakb1), WHICH ARE VALUES OF (a, ZMPrecpeaka, ZMPrecpeakb) FOR FIRST MODEL CURRENT TIME GAIT TO BE GENERATED TO SATISFY BOUNDARY CONDITION, ON THE BASIS OF CURRENT TIME GAIT PARAMETER.

\$700-1

USING SECOND MODEL, TAKE (a1, ZMPrecpeaka1, ZMPrecpeakb1) AS SEARCH INITIAL VALUES AND DETERMINE (a2, ZMPrecpeakb2, ZMPrecpeakb2), WHICH ARE VALUES OF (a, ZMPrecpeakb, ZMPrecpeakb) FOR SECOND MODEL CURRENT TIME GAIT TO BE GENERATED TO SATISFY BOUNDARY CONDITION, ON THE BASIS OF THE ABOVE SEARCH INITIAL VALUES AND OTHER CURRENT TIME GAIT PARAMETER.

S700-2

USING n-TH MODEL, TAKE (am, ZMPrecpeekam, ZMPrecpeekbm)(WHERE m=n-1) AS SEARCH INITIAL VALUES AND DETERMINE (an, ZMPrecpeekkn, ZMPrecpeekbn), WHICH ARE VALUES OF (a, ZMPrecpeeka, ZMPrecpeekb) FOR n-TH MODEL CURRENT TIME GAIT TO BE GENERATED TO SATISFY BOUNDARY CONDITION, ON THE BASIS OF THE ABOVE SEARCH INITIAL VALUES AND OTHER CURRENT TIME GAIT PARAMETER.

S700-n

22 / 27 **FIG.22** 

S700-1

**ENTRY** 

\$750

PROVISIONALLY DETERMINE FIRST MODEL ZMP CORRECTION PARAMETER CANDIDATE at AND BODY INCLINATION RESTORING MOMENT ZMP-CONVERTED VALUE PEAK VALUE CANDIDATES (ZMPrecpeeka1, ZMPrecpeekb1).

S754

\$756

**S760** 

CALCULATE FIRST MODEL CURRENT TIME GAIT UNTIL TERMINATING TIME BY USING FIRST MODEL ON THE BASIS OF PARAMETER OBTAINED BY CORRECTING ZMP TRAJECTORY PARAMETER, WHICH HAS BEEN PROVISIONALLY DETERMINED BY PROVISIONAL DETERMINING PROCESSING OF CURRENT TIME GAIT, BY ZMP CORRECTION PARAMETER CANDIDATE a1, BODY INCLINATION RESTORING MOMENT ZMP-CONVERTED VALUE PEAK VALUE CANDIDATE (ZMPrecpeeka1, ZMPrecpeekb1), AND OTHER CURRENT TIME GAIT PARAMETER.

DETERMINE TERMINAL DIVERGENCE COMPONENT qO[k]

ACCORDING TO THE FOLLOWING EXPRESSION FROM BODY POSITION/VELOCITY (Xe1, Ve1) AT TERMINATING END OF CURRENT TIME GAIT:

 $a01[k] = Xe1 + Vxe1 / \omega 0$ 

DETERMINE TERMINAL DIVERGENCE COMPONENT ERROR error **ACCORDING TO THE FOLLOWING EXPRESSION:** 

errq = q01[k] - q''

\$758

TERMINAL BODY INCLINATION ANGLE ERROR  $\theta$  berr

= n-TH MODEL NORMAL GAIT INITIAL BODY INCLINATION ANGLE

- FIRST MODEL CURRENT TIME GAIT TERMINAL BODY INCLINATION ANGLE
- TERMINAL BODY INCLINATION ANGULAR VELOCITY ERROR  $\omega$  berr = n-TH MODEL NORMAL GAIT INITIAL BODY INCLINATION ANGULAR VELOCITY

S762

- FIRST MODEL CURRENT TIME GAIT TERMINAL BODY INCLINATION ANGULAR VELOCITY

S752

∞

ARE ALL erra.  $\theta$  berr. AND  $\omega$  berr

LEAVE REPETITION LOOP.

WITHIN PERMISSIBLE RANGES?

**S764** 

DETERMINE A PLURALITY OF INITIAL VALUE CANDIDATES (a1 +  $\triangle$  a, ZMPrecpe&ka1, ZMPrecpe&kb1) (a1, ZMPrecpeeka1 + △ ZMPrecpeeka, ZMPrecpeekb1), AND

(a1, ZMPrecpeeka1, ZMPrecpeekb1 + △ ZMPrecpeekb) IN THE VICINITY OF

(a1, ZMPrecpeeka1, ZMPrecpeekb1), AND BASED ON THEM, DETERMINE ERROR CORRESPONDING

TO EACH OF THEM AS DESCRIBED ABOVE.

**S766** 

DETERMINE NEW PARAMETER CANDIDATES (a1, ZMPrecpeaka1, ZMPrecpeakb1) ON THE BASIS OF (a1, ZMPrecpeeka1, ZMPrecpeekb1) AND ERROR CORRESPONDING TO EACH OF INITIAL VALUE CANDIDATES IN THE VICINITY THEREOF.

**FIG.23** 

\$700-n (n≧2)

ENTRY

\$1700

SUBSTITUTE am AND (ZMPrecpeekam, ZMPrecpeekbm)(WHERE m=n-1) INTO n-TH MODEL ZMP CORRECTION PARAMETER CANDIDATE an AND BODY INCLINATION RESTORING MOMENT ZMP-CONVERTED VALUE PEAK VALUE CANDIDATE (ZMPrecpeekan, ZMPrecpeekbn), RESPECTIVELY.

S1704

S1706

CALCULATE n-TH MODEL CURRENT TIME GAIT UNTIL TERMINATING TIME BY USING n-TH MODEL ON THE BASIS OF PARAMETER OBTAINED BY CORRECTING ZMP PARAMETER, WHICH HAS BEEN PROVISIONALLY DETERMINED BY PROVISIONAL DETERMINING PROCESSING OF CURRENT TIME GAIT, BY ZMP CORRECTION PARAMETER CANDIDATE an, BODY INCLINATION RESTORING MOMENT ZMP-CONVERTED VALUE PEAK VALUE CANDIDATE (ZMPrecpeakan, ZMPrecpeakbn), AND OTHER CURRENT TIME GAIT PARAMETER.

DETERMINE TERMINAL DIVERGENCE COMPONENT q0[k] FROM BODY HORIZONTAL POSITION/VELOCITY (Xen, Ven) AT TERMINATING END OF CURRENT TIME GAIT ACCORDING TO THE FOLLOWING EXPRESSION:  $q0n[k] = Xen + Vxen / \omega 0$ 

DETERMINE TERMINAL DIVERGENCE COMPONENT ERROR error ACCORDING TO THE FOLLOWING EXPRESSION: error = q0n[k] - q''

\$1708

TERMINAL BODY INCLINATION ANGLE ERROR  $\theta$  berr

TERMINAL

S1710

= n-TH MODEL NORMAL GAIT INITIAL BODY INCLINATION ANGLE

- n-TH MODEL CURRENT TIME GAIT INITIAL BODY INCLINATION ANGLE
- TERMINAL BODY INCLINATION ANGULAR VELOCITY ERROR  $\omega$  berr = n-TH MODEL NORMAL GAIT INITIAL BODY INCLINATION ANGULAR VELOCITY
  - n-TH MODEL CURRENT TIME GAIT INITIAL BODY INCLINATION ANGULAR VELOCITY

S1712 yes

LEAVE REPETITION LOOP.

∞

S1702

ARE ALL errq,  $\theta$  berr, AND  $\omega$  berr WITHIN PERMISSIBLE RANGES?

S1714

DETERMINE A PLURALITY OF INITIAL VALUE CANDIDATES (an+ \( \triangle a \), ZMPrecpe\( \text{kan} \), ZMPrecpe\( \text{kan} \), ZMPrecpe\( \text{kan} \), AND

(an, ZMPrecpeekan, ZMPrecpeekbn + △ZMPrecpeekb) IN THE VICINITY OF

(an, ZMPrecpeakan, ZMPrecpeakbn), AND BASED ON THEM, DETERMINE ERROR CORRESPONDING TO EACH OF THEM AS DESCRIBED ABOVE.

DETERMINE NEW PARAMETER CANDIDATES (an, ZMPrecpeekan, ZMPrecpeekbn) ON THE BASIS OF (an, ZMPrecpeekan, ZMPrecpeekbn) AND ERROR CORRESPONDING TO EACH OF INITIAL VALUE CANDIDATES IN THE VICINITY THEREOF.

S1716